MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2022/2023

ENT3076 – NANO-SCIENCE

(NE)

10 JULY 2023
09:00 a.m. - 11:00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. 1. This Question paper consists of 4 pages with **4 Questions** only.
2. Attempt **ALL FOUR** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.
4. The lists of physical constants and formulas are given in Page 4.

QUESTION 1

(a) Given the electron affinities of InN and GaN are 4.70 eV and 4.10 eV, and their effective masses of electrons are $0.11m_o$ and $0.20m_o$, respectively. Answer the following:

(i) Determine the number of bound states for electrons in a 10 nm-thick InN/GaN quantum well.

[3 marks]

(ii) Determine the energies of the first **THREE(3)** bound states, respectively.

[6 marks]

(iii) Determine the density of states (DOS) per unit area for total energy of electron gas of 0.25 eV.

[4 marks]

(b) Draw and label clearly the diagrams of *energy* (E) as a function of *density of state* (DOS) for quantum well, quantum wire and quantum dot, respectively. Describe the DOS for each quantum structure.

[6+6=12 marks]

QUESTION 2

(a) Given the list of parameters: electron affinity, energy bandgap and lattice constant, of group III-V semiconductor compounds as shown in **Table 2(a)**, answer the following:

Table 2(a)

Material	Electron Affinity (eV)	Energy Bandgap (eV)	Lattice Constant (Å)
Indium Arsenide, InAs	4.90	0.35	6.06
Indium Phosphide, InP	4.38	1.34	5.87
Gallium Arsenide, GaAs	4.07	1.42	5.65
Aluminum Arsenide, AlAs	3.50	2.16	5.66
Aluminum Antimonide, AlSb	3.60	1.60	6.13

(i) Draw the energy band diagram with respect to the vacuum level for a Type II "staggered gap" quantum well structure using the materials listed in **Table 2(a)**.

[4 marks]

(ii) Calculate and label clearly in the diagram the energy values for conduction bandedge energy (E_c), valence bandedge energy (E_v), conduction band discontinuity (ΔE_c), and valence band discontinuity (ΔE_v), respectively.

[9 marks]

(iii) Determine the lattice mismatch (%) of the chosen materials, and comment on the type of epitaxial growth for the well layer.

[4 marks]

Continued...

(b) Explain the acoustic deformation potential (ADP), optical deformation potential (ODP), polar optical phonon (POP) and piezoelectric (PZ) scattering mechanisms, respectively.

[8 marks]

QUESTION 3

(a) With the aid of suitable diagrams, differentiate the two extreme electron distributions *quasi-isotropic* and *extremely anisotropic* distributions.

[2+6=8 marks]

(b) **Figures 3(b)(i)** and **3(b)(ii)** show the electrons' *temperature* and *electric current* as a function of applied electric field, respectively, for submicron semiconductor structures of different sample thicknesses, $d=d_oL_E$, where L_E is the diffusion energy-relaxation length of the electrons. Discuss the size effects on these **TWO(2)** contexts, respectively.

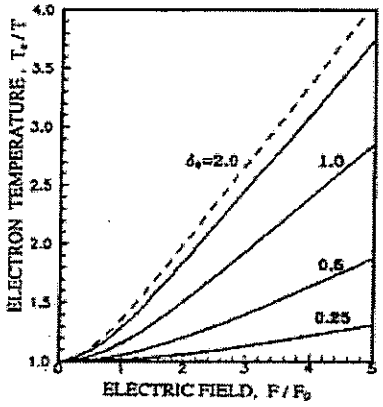

Figure Q3(b)(i)

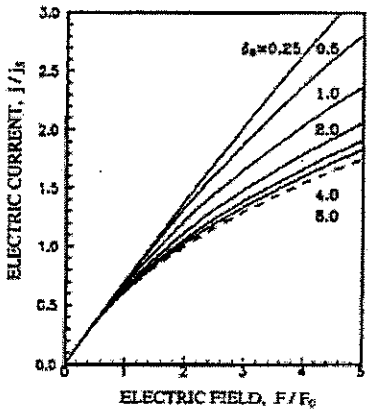

Figure Q3(b)(ii)

[6 marks]

(c) (i) With the aid of a suitable diagram, describe the real-space transfer of electrons in a quantum well structure under high electric field.

[3+5=8 marks]

(ii) How the real-space transfer process could lead to the negative differential resistance (NDR) phenomenon?

[3 marks]

Continued...

QUESTION 4

(a) Differentiate the *coherent tunneling* and *sequential tunneling* in a double-barrier resonant-tunneling structure.

[8 marks]

(b) Optical resonator consists of a cavity sandwiched with two mirrors. Compare the following characteristics of the longitudinal and transverse modes.

(i) Propagation direction

[4 marks]

(ii) Loss and quality factor

[3 marks]

(iii) Spectra (with the aid of diagrams)

[4 marks]

(c) Differentiate the *interband* and *intraband* phototransitions in quantum well structures.

[6 marks]

LIST OF CONSTANTS

Electron mass in free space, $m_o = 9.11\times 10^{-31}$ kg
Planck's constant, $h = 6.63 \times 10^{-34}$ Js
Electronic charge, $e = 1.60 \times 10^{-19}$ C
Boltzmann constant, $k_B = 1.38 \times 10^{-23}$ JK^{-1}
Speed of light, $c = 3 \times 10^{8}$ ms^{-1}
Permittivity of free space, $\varepsilon_o = 8.85 \times 10^{-14}$ Fcm^{-1}
Temperature in Kelvin, T(K) = T(°C) + 273 K

LIST OF FORMULAS

$n = 1 + \text{int}\sqrt{\frac{2m^* V_b L^2}{\pi^2 \hbar^2}}$	$\frac{\rho}{S} = \frac{m^*}{\pi\hbar^2}\sum\Theta(E-\varepsilon_n)$
$\varepsilon_n = \frac{n^2\hbar^2\pi^2}{2m^* L^2}$	$\frac{\rho}{L} = \frac{1}{\pi}\sqrt{\frac{2m^*}{\hbar^2}}\sum_{n1,n2}\frac{1}{\sqrt{E-\varepsilon_{n1,n2}}}\Theta(E-\varepsilon_{n1,n2})$
$\varepsilon_{n1,n2} = \frac{\hbar^2\pi^2}{2m^*}\left(\frac{n_1^2}{L_y^2}+\frac{n_2^2}{L_z^2}\right)$	$N_t = \frac{2\sqrt{2}m^{*\frac{3}{2}}}{3\pi^2\hbar^3}\lvert V_b\rvert^{\frac{3}{2}} L_x L_y L_z$
$\varepsilon_{n1,n2,n3} = \frac{\hbar^2\pi^2}{2m^*}\left(\frac{n_1^2}{L_x^2}+\frac{n_2^2}{L_y^2}+\frac{n_3^2}{L_z^2}\right)$	$m_r = \frac{m_e m_h}{m_e + m_h}$
$a_o^{ex} = \frac{\hbar^2\kappa}{m_r e^2}$	$Ry^{ex} = \frac{m_r e^4}{2\kappa^2\hbar^2}$

End of Paper